Issued January 17, 1914.

HAWAII AGRICULTURAL EXPERIMENT STATION,

E. V. WILCOX, Special Agent in Charge.

Bulletin No. 31.

RICE SOILS OF HAWAII:

THEIR FERTILIZATION AND MANAGEMENT.

BY

W. P. KELLEY,

CHEMIST.

UNDER THE SUPERVISION OF

OFFICE OF EXPERIMENT STATIONS,

U. S. DEPARTMENT OF AGRICULTURE.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1914.

HAWAII AGRICULTURAL EXPERIMENT STATION, HONOLULU.

[Under the supervision of A. C. TRUE, Director of the Office of Experiment Stations, United States Department of Agriculture.]

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LETTER OF TRANSMITTAL.

HONOLULU, HAWAII, *October 1, 1913.*

SIR: I have the honor to submit herewith and recommend for publication, as Bulletin No. 31 of the Hawaii Agricultural Experiment Station, a paper on Rice Soils of Hawaii: Their Fertilization and Management, by W. P. Kelley, chemist. The experiments on rice as carried out by this station indicate quite conclusively that for the most successful production of rice all conditions which tend toward nitrification should be avoided. The application of nitrates has been found to be of little or no avail, and sometimes even positively injurious, while the use of ammonium sulphate brings about greatly increased yields. In harmony with this finding is the evidence that conditions which allow nitrification to take place in rice soils result in a diminished yield of rice. It appears, therefore, that ammonium sulphate should be the form of commercial nitrogen to apply to rice and that rice soils should not be aerated between crops. These results are probably applicable to other regions than the rice lands of Hawaii.

Respectfully,

E. V. WILCOX,
Special Agent in Charge.

Dr. A. C. TRUE,
Director Office of Experiment Stations,
U. S. Department of Agriculture, Washington, D. C.

Publication recommended.
A. C. TRUE, *Director.*

Publication authorized.
D. F. HOUSTON,
Secretary of Agriculture.

CONTENTS.

RICE SOILS OF HAWAII: THEIR FERTILIZATION AND MANAGEMENT.

INTRODUCTION.

The extensive soil investigations that have been made up to the present time have dealt principally with dry lands, in which the moisture and other conditions differ greatly from those prevailing in rice soils. In America in particular very little study has been devoted to submerged lands, and little, indeed, is really known about them. Consequently recommendations for the treatment and management of rice soils are generally based on knowledge gained from experience with dry lands. It is evident, however, that conclusions applicable to dry soils do not necessarily apply to submerged soils such as are used in rice culture, and, in fact, it is well known in oriental countries that rice lands demand different treatment from those devoted to dry-land cultures.

The one condition that is most obviously different in rice soils and dry lands is that of aeration. The fact that aeration is essential to the successful growth of most crops, and the belief that fertility is in some way dependent upon its maintenance, has caused agriculturists to recommend for rice soils practices designed to secure aeration in the belief that this is as essential for successful rice culture as for culture of other crops. Experiments are not wanting, however, which show this to be untrue.

One of the most important matters affecting the culture of rice is the form in which nitrogen is taken up by the crop. It is well known that the degree of aeration in soils determines very largely the form assumed by available nitrogen. This phase of the subject has been reported upon previously by the writer,[1] but will be further emphasized in this bulletin on account of the principle involved and the practical importance attached to it.

In connection with the general soil investigations, which have been under way in the laboratory of the Hawaii station for several years, the rice lands of the Hawaiian Islands have received considerable attention. For a number of years also field experiments with different

[1] Hawaii Sta. Bul. 24.

fertilizers for rice have been conducted by the station. The subject has been approached from a number of standpoints, both practical and scientific, and it is believed the results are of sufficient interest and value to warrant publication at this time.

ORIGIN OF RICE SOILS.

The rice soils of Hawaii are located at or near sea level along the coast and are not extensive in area, amounting to about 10,000 acres, and during recent years the tendency has been to plant other crops on some of the lands hitherto devoted to rice because of low yields, labor difficulties, etc. The extent of the industry, therefore, is on the decline. The soils have their primary origin in basaltic lavas, just as is the case with all the soils of the islands, but in addition they frequently contain varying amounts of coral lime ($CaCO_3$), which has become thoroughly mixed with the lava residues. Whether or not the coral is visible on the surface, in practically all cases the rice lands are underlain at various depths with deep beds of coral limestone. Notwithstanding the fact that the lavas are typical basalts, the chemical and physical properties vary enormously; moreover, the rates of disintegration and the composition of the residuum differ greatly from place to place. Therefore the soils coming from lavas of essentially the same type may be very different in composition and properties. The low lands in and around Honolulu, for instance, having been derived from the disintegration of volcanic cinder, typical black sands, are widely different from the rice lands on the leeward side of Oahu, both in chemical and physical properties. This is especially noticeable in the relative percentages of lime and magnesia.

In most instances the rice soils are strictly alluvial, although on account of the close proximity of the mountains there has been but a limited transportation of the soil materials. The soils in places contain a high percentage of organic matter.

In certain localities, as, for instance, the Hanalei Valley, on Kauai, the soils contain high percentages of clay and are of a close texture. The rice lands around Honolulu, on the other hand, contain quantities of sand and gravel unusual for Hawaiian soils, and as a consequence are open and porous. Samples of soil from all the important rice sections have been examined.

MECHANICAL COMPOSITION.

In view of its bearing on irrigation, etc., the mechanical composition as shown by physical analysis has been determined and is recorded in the following on page 5.

Physical analyses of rice soils.

District.	Fine gravel, 2–1 mm.	Coarse sand, 1–0.2 mm.	Fine sand 0.2–0.04 mm.	Silt, 0.04–0.01 mm.	Fine silt, 0.01–0.002 mm.	Clay, 0.002 mm. or less.	Organic matter and combined water.
Waikiki:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Soil 292	20.91	18.75	22.04	8.69	12.41	7.23	8.71
Subsoil 293	18.61	18.30	22.74	8.10	13.48	9.52	10.77
Fort Shafter:							
Soil 332	1.15	1.61	18.34	16.28	23.88	25.39	14.37
Subsoil 333	1.02	1.28	20.63	17.88	22.11	24.06	14.05
Soil 334	.62	1.63	15.33	15.77	21.73	31.61	15.23
Kailua:							
Soil 337	.35	.69	18.78	13.57	22.92	25.70	18.72
Subsoil 338	.33	.86	18.60	15.97	21.97	23.97	19.54
Soil 339	.13	.22	18.13	20.42	22.37	19.19	21.17
Subsoil 340	.06	.31	16.75	19.27	23.42	22.98	19.41
Kaneohe:							
Soil 343	.05	.19	16.03	30.79	14.64	20.16	15.44
Subsoil 344	.22	.11	15.29	28.94	20.67	21.73	13.20
Waiahole:							
Soil 345	.15	3.09	25.94	20.97	15.96	19.84	15.04
Subsoil 346	.46	3.59	34.44	19.30	10.96	14.29	15.31
Kalaunui:							
Soil 347	.41	.83	21.49	27.45	7.61	6.38	36.14
Subsoil 348	.22	.64	11.29	15.27	20.07	6.19	49.24

The above data show that the rice soils of Oahu, with the exception of those from the Waikiki and Kalaunui districts, are very similar in mechanical composition, and are made up of approximately equal quantities of fine sand, silt, fine silt, and clay. The Waikiki soils, on the other hand, contain relatively small amounts of clay, with correspondingly larger amounts of the coarser grained particles. None of the soils except from this district contains any material coarser than fine gravel, while that from Waikiki contains several per cent of stones, etc. This point is of importance because of its bearing on tillage and drainage. The soils from Kalaunui, on the other hand, are very highly organic, and in places this land is peaty to a considerable degree. The organic matter of this soil, however, retards the passage of water through it, with the result that the amounts of water used in its irrigation are practically normal for the islands.

In the main these soils are to be classified as clay loams with a rather high organic content. The irrigation of all these soils requires relatively large amounts of water on account of their porous nature.

In considering the mechanical composition of Hawaiian soils it should be especially borne in mind that the terms clay, fine silt, etc., have reference only to the size of the particles, and that these are made up of different chemical substances from those that go to make up clay in most continental soils. Furthermore, the properties of so-called clay in Hawaiian soils differ from the properties of other clays. It is not composed primarily of kaolin, but is made up of ferric and aluminum hydrates, together with double silicates of iron and aluminum and perhaps some aluminum silicate. In addition the coarser particles are in the main merely lava fragments on their way toward more complete disintegration. These frequently show under the microscope the characteristic structure of lava. As time goes on the relative proportions of these constituents will change, so that eventually a higher percentage of clay and fine silt will predominate. The upland soils at the present time frequently contain practically no material coarser than silt, with abnormally large quantities of clay. The soils are typical laterites,[1] and in interpreting the analytical results reported herein it is important to bear this in mind.

CHEMICAL COMPOSITION.

The chemical composition of these soils, as determined by the use of the official methods, is shown in the following table:

Chemical composition of rice soils.

District.	Insoluble matter.	Potash (K_2O).	Soda (Na_2O).	Lime (CaO).	Magnesia (MgO).	Manganese oxid (Mn_3O_4).	Ferric oxid (F_2O_3).
OAHU.							
Waikiki:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Soil 292	41.69	0.42	1.47	1.99	9.42	0.27	18.01
Subsoil 293	38.82	.47	1.36	2.48	9.75	.21	21.22
Fort Shafter:							
Soil 332	44.57	.25	.46	.97	.94	.32	18.84
Subsoil 333	45.75	.26	.36	.87	.58	.30	18.48
Soil 334	44.94	.27	.34	.81	.99	.13	17.56
Kailua:							
Soil 337	40.53	.26	.45	.76	.82	.09	19.01
Subsoil 338	42.60	.16	.46	.59	.49	.27	19.67
Soil 339	37.20	.14	.44	.43	.26	.08	24.80
Subsoil 340	38.20	.06	.37	.47	.31	.11	26.15
Kaneohe:							
Soil 343	50.10	.10	.36	1.22	.87	.51	11.20
Subsoil 344	51.15	.15	.38	1.65	.73	.52	10.50
Waiahole:							
Soil 345	50.52	.09	.24	1.20	1.08	.42	17.25
Subsoil 346	48.30	.08	.28	1.63	1.54	.45	16.18
Kalaunui:							
Soil 347	37.82	.12	.31	2.20	.79	.32	7.05
Subsoil 348	27.70	.09	.32	2.76	.78	.35	6.44
KAUAI.							
Hanalei Valley:							
Soil 460	42.40	.16	.10	1.16	2.67	.09	16.22
Soil 461	40.40	.27	.10	.97	3.35	1.16	17.10
Soil 462	47.25	.19	.41	1.18	2.28	.02	14.82
Soil 463	47.00	.17	.34	.97	6.98	.04	18.20
Soil 464	45.18	.15	.42	1.26	1.72	.14	15.32
Soil 465	45.70	.14	.45	1.38	2.65	.23	15.23
Soil 466	45.35	.15	.29	.96	4.16	.15	18.16
Soil 467	43.30	.17	.34	1.16	3.07	.13	15.91

[1] The decomposition of basaltic lavas usually gives rise to soils high in iron and aluminum and relatively low in silica, and while the most finely divided particles are usually referred to as clay, the name is improperly applied. Recently Ulpiani (Staz. Sper. Agr. Ital., 45 (1912) pp. 629–653) suggested that this process be called lateritization in contradistinction to kaolinization, which takes place in the decomposition of orthoclase feldspars.

Chemical composition of rice soils—Continued.

District.	Alumina (Al_2O_3).	Phosphoric acid (P_2O_5).	Sulphur trioxid (SO_3).	Titanic dioxid (TiO_2).	Loss on ignition.	Total.	Nitrogen (N).
OAHU.							
Waikiki:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Soil 292	14.10	0.62	0.08	2.17	9.10	99.34	0.16
Subsoil 293	13.09	.71	.11	2.64	9.92	100.78	.16
Fort Shafter:							
Soil 332	17.10	.32	.03	2.26	13.96	100.02	.16
Subsoil 333	17.42	.26	.10	2.17	13.58	100.13	.13
Soil 334	19.35	.45	.23	1.53	13.70	100.32	.23
Kailua:							
Soil 337	14.94	.76	.26	2.43	18.63	98.94	.44
Subsoil 338	14.50	.68	.26	2.13	18.43	100.24	.42
Soil 339	12.72	.29	.20	2.92	21.10	100.58	.41
Subsoil 340	12.45	.22	.20	2.81	18.41	99.76	.30
Kaneohe:							
Soil 343	20.35	.20	.04	2.24	13.85	100.94	.20
Subsoil 344	20.90	.23	.04	2.37	12.30	100.92	.17
Waiahole:							
Soil 345	14.92	.21	.20	1.64	13.22	100.99	.21
Subsoil 346	15.30	.23	.13	1.60	14.70	100.42	.20
Kalaunui:							
Soil 347	14.40	.19	.31	2.28	34.52	100.31	1.24
Subsoil 348	12.42	.13	.80	1.90	46.70	100.39	1.44
KAUAI.							
Hanalei Valley:							
Soil 460	20.15	.44	.27	2.78	14.15	100.59	.26
Soil 461	20.10	.52	.28	3.00	14.35	101.60	.24
Soil 462	19.12	.53	.35	2.67	12.25	101.07	.20
Soil 463	13.60	.35	.30	2.06	10.42	100.43	.18
Soil 464	20.30	.51	.28	2.93	12.95	101.17	.20
Soil 465	19.95	.72	.31	2.27	11.27	100.30	.15
Soil 466	16.95	.31	.26	2.57	11.80	101.10	.17
Soil 467	20.35	.56	.31	2.70	13.35	101.35	.17

It will at once be seen that these soils differ from normal soils not only in physical properties but also in chemical composition.

The lavas from which these soils have been derived are made up primarily of pyroxenes or amphiboles and soda-lime feldspars, and therefore are characteristically basic. In the disintegration process solution and oxidation play the most important parts, with the result that the soils formed contain iron and aluminum in great quantities, while the potash, soda, lime, and magnesia are largely leached out as silicates. In a few instances the rice soils, however, contain relatively large amounts of lime and magnesia, due partly to admixtures with coral limestone and in part to the type of lava from which they were derived. It is also noteworthy that the ratio of lime to magnesia in these soils is abnormal, the latter sometimes being present in great excess above the former. In view of the interest now taken in the lime-magnesia ratio the relations of these two elements are of special interest, particularly since rice has been extensively studied in connection with this ratio.

The potash content is rather low, while phosphoric acid is generally present in large amounts. From a superficial examination of these analyses it would seem that potash fertilization is needed. It will be shown in connection with the fertilization studies, however, that there is no need for potash fertilizer. The decomposition of the lava fragments is greatly increased by the products arising from the decay of organic matter under the prevailing anaerobic conditions, with the result that potash is rendered soluble at a rate sufficient to supply the needs of rice, but the limited supply of potash present, together with the fact that large amounts of potash are taken up by rice, will sooner or later necessitate the use of potash-bearing fertilizer.

FERTILIZER EXPERIMENTS.

Some fertilizer experiments with rice have already been published by this station.[1] The results were such as to emphasize the need for a more systematic study of this question, and in view of the fact that the yields obtained by the rice growers throughout the islands are frequently unprofitable, a series of fertilizer tests were instituted on the rice trial grounds of the station in the spring of 1909. These experiments were continued on the same plats throughout seven consecutive crops. In Hawaii little or no rotation of crops is practiced, and two crops of rice are grown on the same land each year.

The soil on which these experiments were made had been previously devoted to rice culture and was known to be quite uniform in productivity. After the plats had been laid out, however, an additional crop, without fertilization, was grown for the purpose of determining more definitely their uniformity. The results showed the plats to be extremely uniform throughout, practically the same yield having been obtained from each. The plats were separated by low dikes so constructed as to prevent the lateral movement of fertilizers and irrigation was adjusted so as to insure a constant water supply of about 2 inches in depth above the surface of the soil.

After harvesting the first crop the original plats were divided into two equal portions, which here are to be designated as series A and B. The former were fertilized previous to the time of transplanting the spring crop only, while the latter received the same applications in like quantities to both the spring and fall crops. Previous experience had suggested that nitrogen would prove to be the most needed element, and this was borne out by the results obtained later. The yields obtained, fertilizers applied, etc., are recorded in the tables, using the following values in calculating the cost of fertilizers, profits, etc.: Ammonium sulphate, $80 per ton; superphosphate, $20 per ton; potassium sulphate, $55 per ton; paddy, $0.025 per pound. In calculating the profit or loss, the extra expense incurred from the increased labor attached to making the application of fertilizers, harvesting, and marketing the increased yields, etc., was not included.

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[1] Hawaii Sta. Rpts. 1907 and 1908.

Results of applying fertilizers to spring crop only.

Plat.	Fertilizer.	Yield per acre.						Cost of fertilizer.	Profit (+) or loss (—) per annum.
		Spring crop.		Fall crop.		Total yield per annum.	Increase in paddy per annum.		
		Straw.	Paddy.	Straw.	Paddy.				
	1909—SERIES A.								
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*		
1	None	1,300	1,462	1,950	[1] 1,950	6,662	....	....	....
2	Superphosphate, 225 pounds; Potassium sulphate, 120 pounds	1,641	1,625	2,242	3,250	8,758	9	$5.55	—$5.33
3	Ammonium sulphate, 150 pounds; potassium sulphate, 120 pounds	1,722	2,007	2,667	2,632	9,028	0	9.30	— 9.30
4	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds	2,112	2,128	2,275	3,217	9,732	479	8.25	+ 3.72
5	None	1,267	1,543	2,275	3,347	8,432	....	....	....
6	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds; potassium sulphate, 120 pounds	1,950	2,242	2,925	3,347	10,464	723	11.55	+ 6.52
7	Ammonium sulphate, 300 pounds; superphosphate, 450 pounds; potassium sulphate, 240 pounds	2,762	2,957	2,250	3,152	11,121	1,243	23.10	+ 7.96
8	Ammonium sulphate, 300 pounds	2,405	2,730	2,307	3,315	10,757	1,179	12.00	+17.47
9	Ammonium sulphate, 150 pounds	1,950	2,285	2,502	3,867	10,604	1,286	6.00	+26.15
10	None	1,379	1,528	2,372	3,315	8,594	....	....	....
	1910—SERIES A.								
1	None	1,657	1,527	1,560	[1] 1,202	5,946	....	....	....
2	Superphosphate, 225 pounds; potassium sulphate, 120 pounds	1,690	1,722	1,852	2,015	7,279	0	$5.55	—$5.55
3	Ammonium sulphate, 150 pounds; potassium sulphate, 120 pounds	1,950	1,722	1,560	1,852	7,084	0	9.30	— 9.30
4	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds	1,982	2,047	1,820	2,080	7,929	65	8.25	— 6.63
5	None	1,690	1,885	1,755	2,177	7,507	....	....	....
6	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds; potassium sulphate, 120 pounds	1,917	2,307	1,755	2,307	8,286	552	11.55	+ 2.25
7	Ammonium sulphate, 300 pounds; superphosphate, 450 pounds; potassium sulphate, 240 pounds	2,470	3,055	1,820	2,210	9,555	1,203	23.10	+ 6.97
8	Ammonium sulphate, 300 pounds	2,827	3,347	1,852	2,405	10,431	1,690	12.00	+30.35
9	Ammonium sulphate, 150 pounds	2,250	2,502	1,885	2,535	9,172	975	6.00	+18.37
10	None	1,625	1,397	1,495	[1] 1,300	5,817	....	....	....

[1] Injured by cold water flowing directly onto plat. Not included in averages.

Results of applying fertilizers to spring crop only—Continued.

1911—SERIES A.

Plat.	Fertilizer.	Yield per acre. Spring crop. Straw.	Spring crop. Paddy.	Fall crop. Straw.	Fall crop. Paddy.	Total yield per annum.	Increase in paddy per annum.	Cost of fertilizer.	Profit (+) or loss (−) per annum.
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*		
1	None	1,430	1,332	1,300	1,592	5,654	....	....	....
2	Superphosphate, 225 pounds; potassium sulphate, 120 pounds	1,267	1,527	1,300	1,690	5,784	76	$5.55	−$3.65
3	Ammonium sulphate, 150 pounds; potassium sulphate, 120 pounds	1,852	2,112	1,202	1,527	6,693	498	9.30	+ 3.15
4	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds	1,917	2,372	1,202	1,625	7,116	856	8.25	+13.15
5	None	1,202	1,365	1,267	1,690	5,524	....	....	....
6	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds; potassium sulphate, 120 pounds	2,147	2,470	1,267	1,690	7,574	1,019	11.55	+13.92
7	Ammonium sulphate, 300 pounds; superphosphate, 450 pounds; potassium sulphate, 240 pounds	3,085	3,510	1,300	1,755	9,650	2,124	23.10	+30.09
8	Ammonium sulphate, 300 pounds	2,957	3,380	1,527	2,080	9,944	2,319	12.00	+45.97
9	Ammonium sulphate, 150 pounds	2,535	2,730	1,657	2,242	9,164	1,831	6.00	+39.77
10	None	1,560	1,690	1,397	1,755	6,402	....	....	....

1912—SERIES A.

Plat.	Fertilizer.	Spring crop. Straw.	Spring crop. Paddy.	Fall crop. Straw.	Fall crop. Paddy.	Total yield per annum.	Increase in paddy per annum.	Cost of fertilizer.	Profit (+) or loss (−) per annum.
1	None	1,430	[1] 1,495	....	....	2,925	....	....	....
2	Superphosphate, 225 pounds; potassium sulphate, 120 pounds	1,490	1,690	....	....	3,180	0	$5.55	−$5.55
3	Ammonium sulphate, 150 pounds; potassium sulphate, 120 pounds	2,345	2,567	....	....	4,912	569	9.30	4.92
4	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds	2,795	2,665	....	....	5,460	667	8.25	8.43
5	None	1,430	1,852	....	....	3,282	....	....	....
6	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds; potassium sulphate, 120 pounds	2,470	2,405	....	....	4,875	407	11.55	− 1.38
7	Ammonium sulphate, 300 pounds; superphosphate, 450 pounds; potassium sulphate, 240 pounds	3,705	3,445	....	....	7,150	1,447	23.10	13.07
8	Ammonium sulphate, 300 pounds	4,420	4,095	....	....	8,515	2,097	12.00	40.42
9	Ammonium sulphate, 150 pounds	3,315	3,315	....	....	6,630	1,317	6.00	26.92
10	None	1,885	2,145	....	....	4,030	....	....	....

[1] Injured by cold water flowing directly onto plat. Not included in averages.

Results of applying fertilizers to both spring and fall crops.

1909—SERIES B.

Plat.	Fertilizer.	Yield per acre.					Increase in paddy per annum.	Cost of fertilizer.	Profit (+) or loss (−) per annum.
		Spring crop.		Fall crop.		Total yield per annum.			
		Straw.	Paddy.	Straw.	Paddy.				
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*		
1	None	1,300	1,462	2,242	[1] 2,015	7,019	....	....	....
2	Superphosphate, 225 pounds; potassium sulphate, 120 pounds	1,641	1,625	2,450	3,282	8,998	57	$11.10	−$9.68
3	Ammonium sulphate, 150 pounds; potassium sulphate, 120 pounds	1,722	2,007	2,450	3,867	10,046	1,024	18.60	+ 7.00
4	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds	2,112	2,128	3,185	4,582	12,007	1,860	16.50	+30.00
5	None	1,267	1,543	2,340	3,575	8,725	....	....	....
6	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds; potassium sulphate, 120 pounds	1,950	2,242	3,770	4,582	12,544	1,974	23.10	+26.25
7	Ammonium sulphate, 300 pounds; superphosphate, 450 pounds; potassium sulphate, 240 pounds	2,762	2,957	3,542	5,070	14,331	3,177	46.20	+33.22
8	Ammonium sulphate, 300 pounds	2,405	2,730	3,575	5,200	13,910	3,080	24.00	+53.00
9	Ammonium sulphate, 150 pounds	1,950	2,285	3,250	4,940	12,425	2,375	12.00	+47.37
10	None	1,379	1,528	2,210	3,055	8,172	....	....	....

1910—SERIES B.

Plat.	Fertilizer.	Spring crop Straw.	Spring crop Paddy.	Fall crop Straw.	Fall crop Paddy.	Total yield per annum.	Increase in paddy per annum.	Cost of fertilizer.	Profit (+) or loss (−) per annum.
1	None	1,722	[1] 1,495	1,560	[1] 1,495	6,272	....	....	....
2	Superphosphate, 225 pounds; potassium sulphate, 120 pounds	1,755	1,430	2,145	2,470	7,800	0	$11.10	−$11.10
3	Ammonium sulphate, 150 pounds; potassium sulphate, 120 pounds	2,632	2,860	2,405	3,055	10,952	1,073	18.60	+ 8.22
4	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds	2,405	2,860	2,470	3,445	11,180	1,463	16.50	+ 20.07
5	None	1,755	2,080	2,145	2,762	8,742	....	....	....
6	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds; potassium sulphate, 120 pounds	2,307	2,892	2,665	3,835	11,699	1,885	23.10	+ 24.02
7	Ammonium sulphate, 300 pounds; superphosphate, 450 pounds; potassium, sulphate, 240 pounds	3,055	3,705	3,250	4,267	14,277	3,130	46.20	+ 32.05
8	Ammonium sulphate, 300 pounds	3,185	3,900	3,055	4,322	14,462	3,380	24.00	+ 60.50
9	Ammonium sulphate, 150 pounds	2,470	2,827	2,967	3,867	12,131	1,852	12.00	+ 34.30
10	None	1,722	[1] 1,690	1,495	[1] 2,015	6,922	....	....	....

[1] Injured by cold water flowing directly onto plat. Not included in averages.

Results of applying fertilizers to both spring and fall crops—Continued.

1911—SERIES B.

Plat.	Fertilizer.	Yield per acre.						Cost of fertilizer.	Profit (+) or loss (−) per annum.
		Spring crop.		Fall crop.		Total yield per annum.	Increase in paddy per annum.		
		Straw.	Paddy.	Straw.	Paddy.				
		Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*		
1	None	1,625	[1] 910	1,755	[1] 2,535	6,825	....	....	....
2	Superphosphate, 225 pounds; potassium sulphate, 120 pounds	1,397	1,397	1,787	2,470	7,051	15	$11.10	−$10.78
3	Ammonium sulphate, 150 pounds; potassium sulphate, 120 pounds	2,307	2,502	2,242	3,022	10,073	1,672	18.60	+ 23.20
4	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds	2,502	2,600	2,405	3,445	10,952	2,193	16.50	+ 38.32
5	None	1,332	1,527	1,675	2,437	6,953	....	....	....
6	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds; potassium sulphate, 120 pounds	2,600	3,055	2,600	3,737	11,992	2,940	23.10	+ 50.40
7	Ammonium sulphate, 300 pounds; superphosphate, 450 pounds; potassium sulphate, 240 pounds	3,835	4,485	3,347	4,647	16,314	5,280	46.20	+ 85.80
8	Ammonium sulphate, 300 pounds	3,900	4,420	3,185	4,615	16,120	5,183	24.00	+105.57
9	Ammonium sulphate, 150 pounds	2,535	3,152	2,665	3,900	12,252	3,200	12.00	+ 68.00
10	None	1,430	1,820	1,365	1,917	6,532	....	....	....

1912—SERIES B.

Plat.	Fertilizer.	Spring crop. Straw.	Spring crop. Paddy.	Fall crop. Straw.	Fall crop. Paddy.	Total yield per annum.	Increase in paddy per annum.	Cost of fertilizer.	Profit (+) or loss (−) per annum.
1	None	1,430	1,755	....	....	3,185	....	....	....
2	Superphosphate, 225 pounds; potassium sulphate, 120 pounds	1,495	1,885	....	....	3,380	0	$5.55	—$5.56
3	Ammonium sulphate, 150 pounds; potassium sulphate, 120 pounds	2,730	2,665	....	....	5,495	683	9.30	7.77
4	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds	3,055	2,990	....	....	6,045	1,008	8.25	16.95
5	None	1,560	2,047	....	....	3,607	....	....	....
6	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds; potassium sulphate, 120 pounds	3,120	2,925	....	....	6,045	943	11.55	12.08
7	Ammonium sulphate, 300 pounds; superphosphate, 450 pounds; potassium sulphate, 240 pounds	5,330	4,322	....	....	9,652	2,340	23.10	35.40
8	Ammonium sulphate, 300 pounds	4,680	4,095	....	....	8,775	2,113	12.00	40.82
9	Ammonium sulphate, 150 pounds	4,877	3,120	....	....	7,995	1,138	6.00	22.45
10	None	Lost.	2,145	....	....	....	....	....	....

[1] Injured by cold water flowing directly onto plat. Not included in averages.

Summary of the results of applying fertilizers to seven crops of rice.

Plat.	Fertilizer per crop.	Series A—one application annually.				Series B—two applications annually.				
		Paddy.		Total cost of fertilizer.	Total profit or loss.	Paddy.		Total cost of fertilizer.	Total profit or loss.	Average profit (+) or loss (—) per acre.
		Total.	Increase.			Total.	Increase.			
		Pounds.	*Pounds.*			*Pounds.*	*Pounds.*			
1	None	[1]10,560	....	....	....	[1]11,567	....	....	....	....
2	Superphosphate, 225 pounds; potassium sulphate, 120 pounds	13,519	26	$22.20	—$21.55	14,559	0	$38.80	—$38.80	—$5.54
3	Ammonium sulphate, 150 pounds; potassium sulphate, 120 pounds	14,419	926	37.20	— 14.05	19,978	4,908	65.10	57.60	+ 9.39
4	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds	16,134	2,641	33.00	33.02	22,050	6,980	57.75	116.75	+16.69
5	None	13,857	....	....	....	15,971	....	....	....	....
6	Ammonium sulphate, 150 pounds; superphosphate, 225 pounds; potassium sulphate, 120 pounds	16,668	3,175	46.20	33.17	23,268	8,198	80.85	124.10	+17.73
7	Ammonium sulphate, 300 pounds; superphosphate, 450 pounds; potassium sulphate, 240 pounds	20,084	6,591	92.40	72.37	29,453	14,383	161.70	197.87	+28.27
8	Ammonium sulphate, 300 pounds	21,352	7,859	48.00	148.47	29,282	14,212	84.00	271.30	+38.76
9	Ammonium sulphate, 150 pounds	19,476	5,983	24.00	125.57	24,091	9,021	42.00	183.52	+26.22
10	None	13,130	....	....	....	14,170	....	....	....	....

[1] Injured by cold water flowing directly onto plat. Not included in averages.

The results of these experiments justify the conclusion that for the present at least this soil is in need of nitrogen only. Little or no effects were produced in any case from the use of superphosphate or potassium sulphate, either when applied with or without ammonium sulphate. It is the custom of the rice growers to apply fertilizer, when used at all, to the spring crop only, believing that the more unfavorable weather conditions at that time necessitate the use of stimulants, whereas under the more favorable conditions that prevail during the late summer and early fall fertilizers are less needed. Moreover, it has been considered that the residual effect resulting from the spring application makes itself felt in the fall crop. The above experiments prove conclusively that neither of these opinions is justified. The growth of the fall crop, when more favorable weather prevailed—i. e., higher temperature and longer days—was affected to approximately as great extent by ammonium sulphate as was that of the spring crop. On the whole there appeared no evidence of a cumulative effect even from the heaviest application when made twice annually.

From the data showing the profit and loss it is noteworthy that the application of 300 pounds of ammonium sulphate proved the most economical, either when applied to the spring crop only or to both spring and fall crops, and that in the latter case the profits were very large. So far as these experiments go, they show in addition that the yields can be maintained at a high point and good profit be made under the system now employed, provided the proper fertilizer be used. This is not to be interpreted, however, as being a recommendation of the system now in use, since it has been shown (p. 19) that with the rotation of crops, involving the plowing under of a legume, still greater yields can be obtained. The rotation system is far more rational and permanent and ought to be employed on all rice lands.

It has been found in other countries that the continued application of ammonium sulphate tends to produce acidity in the soil due to the fact that the sulphate ion tends to accumulate in the soil. The occasional application of lime, however, will correct this defect. The highly basic character of Hawaiian soils, on the other hand, particularly the rice soils, justifies the belief that the production of acidity from the use of ammonium sulphate will be far removed in point of time. It is of interest in this connection that the annual application for over 60 years of 300 pounds of ammonium sulphate per acre at Rothamsted to a soil containing considerable amounts of calcium carbonate (probably 100 tons per acre in the first 7 inches) has not produced injurious acidity. The soil on which the above rice experiments were conducted contains a relatively high percentage of lime and magnesia, particularly the latter, but neither of these is present as carbonate in more than very limited amounts. The carbon dioxid content of the soil is low, not more than 0.10 per cent. The iron and aluminum, however, occur largely as hydrates which give to the soil its basic character, and which we may reasonably believe will prevent the accumulation of injurious acidity. It is of further interest to note that the application of lime has been shown to cause a decrease in the yields of rice on this soil.

It would not be safe, however, to recommend ammonium sulphate as the only fertilizer to be applied to the rice lands of the islands generally, since the effects of fertilizers frequently vary widely on different soils. In order to throw further light on this question some experiments have been conducted cooperatively on other rice lands, which resulted in showing that ammonium sulphate produced practically as large increases as a complete fertilizer. At Kailua, for instance, approximately 60 per cent increase in yield was produced both by 150 pounds of ammonium sulphate and by a complete fertilizer containing an equal amount of ammonium sulphate.

As already pointed out, the rice soils, as a rule, are rich in phosphoric acid but contain relatively small amounts of potash. While it is true that rice takes up a large amount of potash only a comparatively small part of it enters the grain. In addition, only a comparatively small portion of the straw is really removed from the land, it being the practice to leave about one-half of it on the ground at the time of harvesting, while the remaining portion is used for bedding, etc., a large part of which sooner or later is returned to the soil. Furthermore, whenever manure is accessible the Chinese rice growers cart large quantities of it onto the lands, thus considerably augmenting the potash supply. In view of these facts, then, it is hardly to be supposed that potash fertilizer will be required for many years. In the main, therefore, nitrogen fertilizers only are recommended for Hawaiian rice lands.

In this connection the question of the form of nitrogen best suited to rice naturally arises. Experimental data have been obtained on this subject which permit the drawing of definite conclusions.

THE FORM OF NITROGEN FOR RICE.

One of the most generally accepted teachings in all agricultural literature, based, however, mainly upon experiments with dry-land crops, is that of the high availability of nitrates, it being considered that of all the forms of nitrogen nitrate is the most readily taken up from the soil and used as food by plants. As a result of the prevalence of this view nitrates have been used for rice in America, and indeed sodium nitrate still is recommended at the present time for this crop by some authorities.

It has been known in oriental countries for some time, however, that nitrate is not the most profitable form of nitrogen to apply to rice. Nagaoka,[1] in Japan, demonstrated in 1905 the superiority of ammonium sulphate in a series of pot experiments. He found that while the effects produced by nitrates were variable and discordant the yields were greatly increased in every instance by the use of ammonium sulphate. As a result of his experiments Nagaoka concluded that the value of ammonium sulphate and nitrates stand in the ratio of 100 to 40.

In 1907 Daikuhara and Imaseki[2] also found ammonium sulphate to be much more effective for wet-land rice than either sodium nitrate alone or a combination of the two forms. The value of nitrate was also found to be considerably less when applied in conjunction with organic manures. Likewise it has been shown in several of the Provinces of India that other forms are superior to nitrates. Coleman and Ramachandra Rao,[3] for example, pointed out that organic fertilizers produced a marked stimulation of the growth of rice in Mysore, while niter had but little effect. In 1911 the writer[4] pub-

[1] Bul. Col. Agr., Tokyo Imp. Univ., 6 (1904), pp. 285–334.
[2] Bul. Imp. Cent. Agr. Expt. Sta. Japan, 1 (1907), No. 2, pp. 7–36.
[3] Dept. Agr. Mysore, Gen. Ser. Bul. No. 2, 1912.
[4] Hawaii Sta. Bul. 24.

lished the results of experiments conducted at the Hawaii station which showed the great superiority of ammonium sulphate over different nitrates.

Notwithstanding these facts some American writers continue to recommend sodium nitrate for rice and to discuss rice soils from the same standpoint as dry lands.

It is not necessary to go into a theoretical discussion of this question at this time further than to state that abundant experimental evidence has already been brought forth in various parts of the world to prove that nitrate is not the only form of nitrogen available to plants. Results obtained at the Hawaii station show that nitrate can hardly be considered to be the principal source of combined nitrogen for many plants when grown in the state of nature. It is known that nitrates are ill suited to assimilation by rice.

To study the practical effects produced on the growth of rice by ammonium sulphate and nitrate nitrogen, respectively, a series of plats was arranged alongside of those used in the experiments discussed above. To one plat ammonium sulphate and to another nitrate of soda was applied before the time of planting. To other plats ammonium sulphate and sodium nitrate were applied in smaller quantities, the same being repeated at intervals of 10 days until six applications had been made. To each plat the total amount of nitrogen applied per acre was the same, and the experiments were repeated for three successive crops. The results follow:

Comparison of ammonium sulphate and sodium nitrate on rice.

Nitrogen applied.	Fall crop, 1909.			Spring crop, 1910.			Fall crop, 1910.		
	Straw.	Paddy.	Total.	Straw.	Paddy.	Total.	Straw.	Paddy.	Total.
	Lbs.	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*
Ammonium sulphate (applied before planting)	3,168	4,603	7,771	3,316	3,564	6,880	2,920	4,010	6,930
Sodium nitrate (applied before planting)	1,881	2,475	4,356	2,029	2,128	4,157	2,227	3,312	5,539
Ammonium sulphate (applied in six applications)	2,475	3,465	5,940	2,772	3,078	5,850	2,722	3,762	6,484
Sodium nitrate (applied in six applications)	2,277	2,623	4,900	1,633	2,079	3,712	1,831	2,427	4,258
Check	....	....	....	1,930	2,178	4,108	2,145	2,762	4,907

From the above yields it is apparent that nitrate of soda produced only slight increases either when applied before transplanting or at intervals during the growth of the crop. Ammonium sulphate, on the other hand, brought about notable increases in every instance, the larger harvests having been obtained from the single application before planting. The repeated applications were made for the purpose of guarding against the loss of nitrate through leaching, but this appeared to have no advantage over the single application.

From pot experiments, where drainage was entirely prevented, the great superiority of ammonium nitrogen over nitrate was again demonstrated. In a series of pot experiments with the use of sterile quartz sand, it was found that where nitrate was the only form of combined nitrogen present rice made very poor growth, whereas ammonium forms seemed to be well suited to its needs. The net result of all these experiments forces the conclusion that nitrate is not a suitable form of nitrogen for rice, but that ammonium compounds are well adapted to its needs.[1]

In the rice-producing countries of the Orient organic manures are the chief source of nitrogen applied to rice soils. It has long been the custom of the Chinese and Japanese to grow some legume between crops for the purpose of enriching the soil. Sometimes the legume is grown on one field, cut, and then distributed over others, so as to gain the benefit of green manuring with as little interruption in the growing of rice as possible. In addition, all sorts of organic nitrogenous substances are freely applied. In Hawaii, on the other hand, almost no rotation is practiced.

From a single experiment conducted by the agronomist of this station, however, it was found that by plowing under a few months' growth of alfalfa just previous to the planting of rice the yield was 50 per cent greater than has ever been obtained on this soil by the application of any commercial fertilizer. In this experiment the alfalfa was grown on one plat, but was cut and applied to another, so that the effects may be attributed to the organic manure directly rather than to a combination of aeration and other effects, the soil being prepared and submerged very soon after making the application. Moreover, the application of different organic nitrogenous fertilizers at various times has always resulted in substantial increases in the yield of rice on this soil. In a series of pot experiments, for example, soy-bean cake was compared with ammonium sulphate. In this experiment nitrogen from each of the two sources was applied at the rate of 70 pounds per acre. The yields obtained were as follows:

Ammonium sulphate versus soy-bean cake as fertilizers for rice.

Treatment of plat.	Straw.	Paddy.	Total.
	Grams.	*Grams.*	*Grams.*
Ammonium sulphate	215	138	353
Soy-bean cake	167	122	289
Check	80	61	141

From the above data it will be seen that soy-bean cake brought about an increase of 100 per cent in the yield, but was considerably inferior in this respect to ammonium sulphate. The reasons for the

[1] The full data with reference to the assimilation of different forms of nitrogen by rice and a more complete bibliography of this subject will be found in Hawaii Sta. Bul. 24.

superiority of ammonium sulphate over organic forms of nitrogen are discussed in greater detail on page 21. In this connection it is of interest to point out that the plant absorbs the principal part of its nitrogen during the early period of its growth;[1] readily available nitrogen therefore is needed when the rice is young, and since the production of available nitrogen from organic forms requires considerable time the application should be made some time in advance of planting, a precaution that was not taken in the above experiments. Through a period of years, however, the total effects would probably become more nearly equal.

AMMONIFICATION AND NITRIFICATION IN RICE SOILS.

The analysis of a number of rice soils taken from the field when wet and analyzed immediately has shown that rice soils contain considerable quantities of ammonia, varying from a few parts up to as much as 50 or 60 parts per million.[2] On the other hand, in the submerged condition nitrate is rarely found in more than mere traces, frequently being entirely absent.

Since good effects are known to follow the use of organic manures, and, furthermore, that ammoniacal nitrogen is especially effective with rice, it becomes a matter of interest to ascertain whether or not ammonia is formed in rice soils at rates sufficient to supply the needs of rice.

Accordingly a series of ammonification experiments were carried out with dried blood as the source of nitrogen, using varying amounts of water, starting in with the air-dry condition and increasing the amounts of water applied up to and beyond the saturation point. One hundred gram portions of soil were placed in tumblers with 2 grams of dried blood added to each. After an incubation period of seven days the ammonia was determined by distilling with magnesium oxid into standard acid. The results obtained were as follows:

Influence of varying amounts of water on the ammonification of dried blood.

Water added.	Nitrogen found as ammonia.		Water added.	Nitrogen found as ammonia.	
	Soil 292.	Soil 461.		Soil 292.	Soil 461.
	Mg.	*Mg.*		*Mg.*	*Mg.*
None (soil air dry)[3]	2.2	3.9	35 cc	131.1	86.8
5 cc	2.2	5.1	40 cc	90.5	85.4
10 cc	37.8	4.3	45 cc	[4] 54.5	71.2
15 cc	164.9	25.5	50 cc	50.7	65.3
20 cc	165.5	41.2	55 cc	48.2	52.4
25 cc	164.6	53.2	65 cc		[4] 15.1
30 cc	140.1	59.0	70 cc		16.1

[1] Hawaii Sta. Bul. 21.

[2] Fraps also showed in 1906 that ammonification takes place much more vigorously in rice soils of Texas than does nitrification (Texas Sta. Bul. 82).

[3] Each soil contained about 5 per cent moisture.

[4] Saturated.

It is here seen that ammonification proceeded at a slow rate only, if at all, until a certain moisture content was reached (about 10 per cent in the case of soil 292 and 15 per cent with that of 461), above which vigorous ammonification took place, which steadily increased up to an approximate two-thirds saturation, then decreased as complete saturation was approached. There was, however, active ammonification in the completely saturated soils. This seems to prove that ammonia is formed in submerged soils and that organic nitrogenous fertilizers will give rise to nitrogen available to rice under conditions that prevail in rice cultures.

As is well known, the formation of ammonia results from the activity of a wide range of soil organisms, bacteria and fungi, some of which are aerobic and some anaerobic. While the above data show that ammonification is more active with moisture supplies below the saturation point, being greatest at approximately two-thirds saturation; nevertheless, the fact that ammonification can take place in saturated soils is of very great importance in the growth of rice. It makes possible the production of available nitrogen in rice soils without the necessity of employing cultural methods that are primarily designed to bring about aerated conditions.

Free oxygen being essential to nitrification, it seems justifiable to conclude that nitrification does not take place to any considerable extent in a submerged soil. In order to throw positive light on the question, however, search was made for nitrates in various submerged soils about Honolulu, but in no instance was more than a few parts per million found. In some laboratory experiments it was further found that practically no nitrification took place in submerged soils.

The process of denitrification, however, is of considerable importance in this connection. As is well known, free nitrogen gas may be one of the products of the decay of organic manures. Likewise, it is also known that certain denitrifying bacteria break down nitrates into nitrites, ammonia, and finally into free nitrogen gas. The conditions under which the denitrifying bacteria function are extremely varied, but the two conditions most favorable for their activity are a source of food supply and a lack of free oxygen. In the rice soils of Hawaii these conditions are abundantly met; the high content of organic matter guarantees a source of food, while supersaturation excludes the air.

As indicated above, the denitrification processes may be conveniently divided into two classes, (1) those causing a liberation of nitrogen from organic materials, and (2) those bringing about a reduction in the nitrates present. The latter of these has been the subject of considerable study at the Hawaii station.

In pot experiments conducted some time ago for the purpose of studying the nutritive value of different forms of nitrogen it was found that in every instance the addition of nitrate to submerged soil resulted in the formation of comparatively large amounts of nitrite within a few days after the time of application. In sand cultures similar effects were observed except where complete sterilization was effected. Furthermore, wherever any considerable amount of nitrite was formed, more than 5 to 6 parts per million, toxic effects were produced, while still greater amounts caused the rice to turn yellow and later to die.

Nitrite, however, was not produced to any considerable extent when organic ammoniacal nitrogen was the only form of combined nitrogen present. A further objection to the use of nitrates as fertilizer for rice is found in the fact, therefore, that nitrates become reduced to nitrites, which are extremely poisonous to rice. Nitrate, then, is unsuited to the nutrition of rice, and in turn may give rise to a substance that is distinctly poisonous.

THE MANAGEMENT OF RICE SOILS.

During the past few years an increasing amount of study has been given to the question of soil management and cultural methods, the rotation of crops, and various methods of soil treatment are coming to be viewed in their relation to this general question. Investigations on special phases of this subject have thrown new light on the important question of soil fertility in general and on that of submerged soils in particular.

In an investigation on the solubility of the island soils[1] some data of interest in this connection were recently obtained. Likewise Coleman and Ramachandra Rao[2] studied the effects on the yield of rice of aerating the soil.

The solubility of substances in submerged soils has been found to be abnormally high, the amounts of the several mineral constituents going into solution in water having been found to be considerably greater than were obtained from any of the dry-land soils of the islands.[1] After the wet soil was allowed to thoroughly dry out, however, the solubility in water was found to be greatly decreased, falling to about the same degree as that of dry lands. Similar data have also been obtained by Coleman and Ramachandra Rao, in Mysore.[2] This seems referable in the main to soil colloids and the formation of soil films in the air-dried state. The overcoming of film pressure and diffusion of dissolved materials upon resubmergence require considerable time, so that the amount of soluble plant

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[1] Hawaii Sta. Bul. 30.

[2] Dept. Agr. Mysore, Gen. Ser. Bul. No. 2, 1912.

food coming into contact with the absorbing root surfaces of rice would be considerably less when planted in a soil that had been thoroughly dried out. Later the mineral constituents would, of course, regain their former state of solubility, but just how much time would be required for the reestablishment of a permanent concentration can not be definitely stated. It seems certain, however, that a lowering of the availability of the mineral constituents would temporarily result from a thorough drying out of the soil.

It is now the practice of the growers, both on the mainland and in Hawaii, to plow their rice lands some weeks before the flooding time, in the latter case immediately following each harvest, so as to permit as much aeration of the soil as possible. As would be expected the aeration prevents nitrification, so that by the time a new crop is planted nitrate has accumulated to a considerable extent. Upon resubmergence the nitrate thus formed becomes partially leached out of the soil and in part converted into poisonous nitrites. The nitrification therefore leads to a direct loss of nitrogen on the one hand and to the formation of a substance toxic to rice on the other. If, however, Hawaiian rice soils are not plowed or cultivated after the water is turned off and the previous crop harvested little or no nitrification sets in. The puddled state of the soil and its compacted condition effectively exclude air. It is only after cultivation and consequent aeration that active nitrification sets in.

Unfortunately no experiments showing the practical effects on the growth of rice as produced by aeration against nonaeration have been conducted at this station. Such experiments, however, have been made in Mysore, the results of which are in complete harmony with the inferences drawn from the nitrogen transformations above referred to. As a result of experiments carried on through two years, Coleman and Ramachandra Rao [1] found that a considerable gain in the yield of rice was obtained by leaving the land in the unplowed condition during the time between crops, the plowing for the new crop being deferred until just before the new crop was planted. By growing a legume between rice crops all needed aeration can be brought about; while the nitrates formed during this period would be absorbed to a large extent by the legume, and in addition free nitrogen from the air would be added to the soil through the growth of the legume. Upon plowing under the legume ammonification will set in, thus furnishing available nitrogen for the next rice crop. The nitrogen requirements of the rice would therefore be met and other beneficial effects that are believed to result from the rotation of crops would be secured. There is little ground

[1] Loc. cit., p. 9.

to doubt that better conditions would thus be established and greater profits obtained.

In the carrying out of the experiments reported in this bulletin assistance has been rendered by various members of the station staff, to whom thanks are hereby extended.

SUMMARY.

(1) Hawaiian rice soils have originated from basaltic lava, but also contain small amounts of coral limestone.

(2) In texture most of the rice lands are clay loams, and contain approximately equal quantities of fine sand, silt, fine silt, and clay.

(3) In chemical composition these soils are quite similar, with the exception of those from the Waikiki and Kaulaunui districts, the former of which contain abnormal amounts of magnesia, while the latter are highly organic. In general, the nitrogen and phosphoric acid are high, while the potash is low, due largely to the solubility of potash, which is leached from the soil.

(4) From fertilizer experiments carried on through seven crops it was found that the application of 150 pounds per acre of ammonium sulphate produced notable increases in the yield, but 300 pounds per acre proved the more profitable. Potash and phosphoric acid were without effect. The application of ammonium sulphate to both the spring and fall crops yielded considerably more profit than when made to the spring crop only. The residual effects on the fall crop from the spring application are small. The immediate effects obtained from making the application to the fall crop were about the same as those obtained with the spring crop.

(5) A complete fertilizer proved no more effective than ammonium sulphate alone, whereas the application of both ammonium sulphate and potassium sulphate caused a decrease as compared with that obtained from ammonium sulphate alone.

(6) Nitrogenous fertilizers only are recommended for Hawaiian rice soils, and for immediate effects a given amount of nitrogen in the form of ammonium sulphate will produce greater returns than from organic sources. Under no circumstances should nitrates be used as fertilizer for rice.

(7) With nitrate as the only source of combined nitrogen for rice poor growth results. In addition nitrates in submerged soils become reduced to nitrites, which are poisonous to rice. Ammoniacal nitrogen, on the other hand, is well suited to the needs of rice.

(8) Very little nitrification takes place in submerged soil; ammonification, however, goes on, not so vigorously as in aerated soils, but sufficiently to supply the nitrogen needs of rice, provided sufficient organic matter is present in the soil.

(9) A rotation of crops, including the plowing under of a legume, is recommended. It is believed a system can be worked out whereby a legume can be grown between crops and then plowed under, thus gaining the benefits of the rotation and at the same time permitting the growing of two crops of rice annually.

(10) Rice soils should not be plowed and then allowed to lie fallow between crops. Nitrification sets in immediately after aerated conditions are produced and the nitrates thus formed become converted into poisonous nitrites upon resubmergence, or are lost through leaching. When no rotation is practiced it is better to leave the land unplowed until just before planting the next crop.

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